Traffic Signal Control for Urban Trunk Road Based on Wireless Sensor Network and Intelligent Algorithm

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Abstract- Based on the analysis for the present research on controlling urban trunk road, a intelligent control method for urban trunk road based on wireless sensor and fuzzy neural network was proposed. In this method, we took two layers of WSN structure. The first one was data collecting layer, which consisted of traffic information collecting nodes and sink nodes. Data collecting layer was responsible for collecting vehicle information at single crossing, transmitted to the second layer after data fusion. The second one was control layer, composed of traffic light controller nodes in which fuzzy neural

controller was nested. Traffic light controller nodes were used to accept the traffic data detected by the first layer, and fuzzy neural controller determined the signal cycle at artery, and on-line adjusted the green ratio at all directions on crossroads to accomplish traffic light control. Simulating results showed that the method is superior to the common fuzzy control, effectively reducing queue length, so as to reach the purpose of decreasing vehicle delay.

Index terms*: wireless sensor network, intelligent traffic, fuzzy neural network, queue length.*

I. INTRODUCTION

With the rapid development of modern cities and fast increasing amount of vehicles, ITS has become crucial nowadays. Traditional traffic information detection systems can't meet the requirements of deployment convenience, detection accuracy and overall cost. Wireless sensor networks colligated embedded systems and Wireless communication and micro-electronics technical, has potential wide prospect of applications. WSN has a lot of advantages including no wiring and low cost, which is gradually applied in the fields correlated with data acquisition and detection, such as intelligent traffic system, and satisfying effects have been achieved. Research shows wireless sensor network has outstanding features that can provide an effective measure for data acquisition in intelligent traffic system[1,2,3].

Fuzzy control is especially suitable for the control of city traffic system with large randomness, where a mathematic model is not needed to be set up for it[4]. Fuzzy theory is efficient for processing fuzzy information, but the rules produced by it are quite rough. Neural network is strong at nonlinear mapping, by which rules can be improved through learning and can efficiently increase control precision[5].

After making a comprehensive analysis for research in crossing signal control both at home and abroad, we find that until now control schemes taking use of WSN combined with fuzzy neural network to control traffic artery are scarce and especially are not perfect in theory and practice. Therefore, on the basis of predecessors' research in this paper we put forward a low-cost, strong-utility rank control system for traffic artery based on the combination of wireless sensor and fuzzy neural network. WSN is responsible for detecting the number of vehicles entering crossing at all directions on traffic artery to accomplish wireless real-time transmission. Making least average queue length as its objective, fuzzy neural control method was used to on line adjust prime green light delay in all directions at crossing and signal cycle on artery, and outputted them to traffic signal controller to accomplish intelligent control.

II. CONTROL MODEL AND ALGORITHM

a. Control model

The system takes two layers of control model, as shown in figure 1. The first one is data collecting lay, composed of traffic information collect nodes and sink nodes. They make up of cluster, while sink nodes work as the heads of the cluster, and other data collecting nodes work as members. Traffic information collecting nodes are disposed at each crossing for traffic count. Sink nodes are used to collect the data from data collecting nodes, transmitted to the second layer after data fusion. The second one is control layer, which is composed of traffic light controller nodes. Fuzzy neural controller is nested in the traffic light controller node and used to determine signal cycle at artery, and adjusted on-line the green ratio at all directions on crossings to accomplish traffic light control.

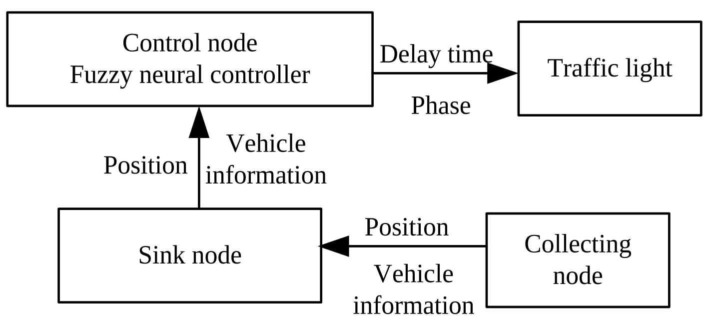

Figure 1. WSN control model

b. Control algorithm

In traffic control system, harmonious cycle each crossing cycle cannot change too frequently, otherwise, the loss of traffic delay brought by solution changing would exceed the benefit brought by new scheme[5]. In this article we took eight cycles as a time period, in which keeping signal and phase used in artery not changed, but the green ratio could be real-time adjusted.

Step 1: The traffic light controller nodes calculate the phase difference χ_i (i=1, 2, 3, … , m) among the crossings at the arteries, and unify the cycle T and the green ratio at each crossing according to the previous traffic flow data. Data are sent to the traffic light control nodes at the crossings to initialize the cyclic variable n=0.

Step 2: In the cycle T period, the traffic light controller nodes at the artery crossings start the green light signals in sequence, basing on the phase difference ωi. Using the fuzzy neural control method to adjust the phase difference between crossings at the end of a given cycle time, the traffic light controller nodes, which use the data sent by the terminal node, compute the vehicle queue length P of the green light phase and the queue Q of the next green light phase at the crossings.

Step 3: Use n=n+T to check the validity of n>8T. If it is valid, then go to step 4. If not, return to step 2.

Step 4: Using the fuzzy neural control method, the traffic light controller nodes use the data of the traffic flow and the green ratio transmitted by the sink nodes at the crossings to determine the cycle and phase difference so that the average vehicle queue length is kept to a minimum. Return to Step 2.

III. WIRELESS SENSOR NETWORKS AND ITS NODE HARDWARE DESIGN

a. Wireless sensor traffic information collecting network

Wireless traffic information collecting network is made up of wireless traffic information collecting nodes, wireless information sink nodes and traffic light control nodes. as shown in Figure 2.Information collecting nodes are disposed on the roadside, collecting signals on observation area, processing original signals and extracting vehicle information, and transmitting traffic information through wireless network. The sink nodes are responsible for gathering and fusing the data from all the information collecting nodes and transmitting traffic information to traffic control nodes[6].

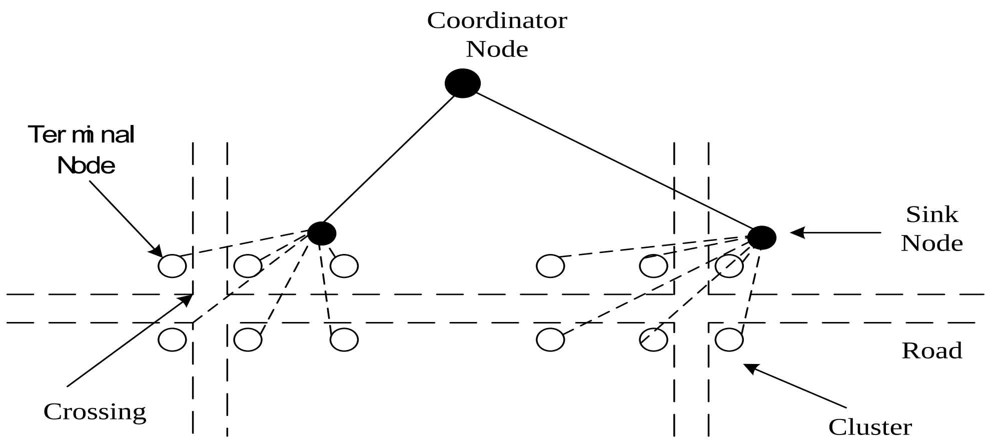

Figure 2. Wireless traffic information collecting network

b. Wireless traffic information collecting node

Each wireless sensor node is made up of data acquisition module, processor module, wireless communication module and power supply module[7], as shown in Figure 3.

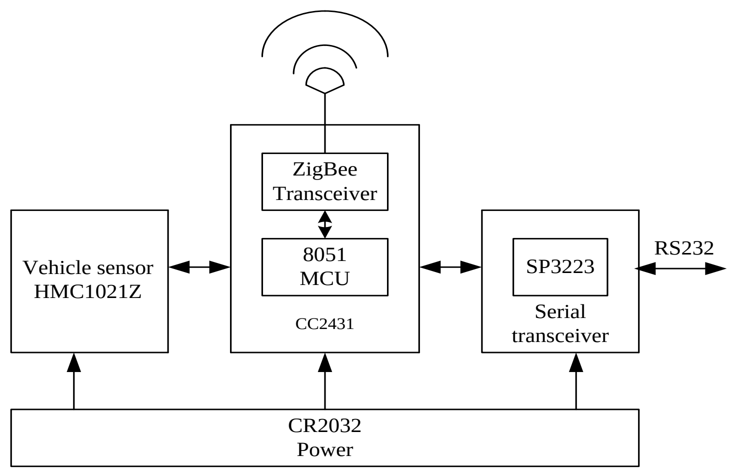

Figure 3. Structure of Sensor node

(1) Processor module

The data acquisition module is responsible for acquiring vehicle information from each lane. The data-processing module consists of a Chipcon's SoC chip CC2431, which is a new generation of a Zigbee wireless single chip computer with a positioning engine. The CC2431 integrates the Zigbee RF front-end, the memory and the controller into a single chip. It includes an 8051 processor kernel and an ieee802.15.4 RF transceiver, which is a high-performance RF transceiver

CC2420, and supports the Zigbee low-rate communication standards. It has a 32MHz internal clock and its power consumption is only 7.0 mA at the work peak level in the processor core. Wireless transceiver consumes 24 ~ 27 mA. It supports a 4-grade low-power mode. To implement wireless data transmitting and receiving, it controls the operation of the entire sensor node, including the storing and processing of the data collected. The single-chip microcomputer in CC2431 communicates with the sensor by its figure port.

(2) Wireless communication module

For the CC2431 radio transceiver, as the CC2431integrates with the 8051 kernel and the wireless transceiver module into a chip, so that the circuit design is simplified. The transmitter is based directly on the frequency inverter, in which the to-be-sent data will be sent to the buffer of 128 bytes, while the head frame and the starting frame are automatically generated by the hardware. According to the IEEE802.15.4 standard, every four bits of to-be-sent data flow will be spread to the D/A converter by a 32 yard slice of spread-spectrum sequence. After going through the low-pass filter and the mixing of frequency, the RF signal will eventually be modulated up to 2.4 GHz, amplified and emitted by the antenna.

(3) Sensor module

We have used a Honeywell HMC1021Z magnetic sensor with the resolution of 85μGauss and the sensitivity of 1mV/V/Gauss for the perception of vehicle information. A Wheatstone bridge is integrated inside the magnetic sensor, while the resistance of the arm (nickel-iron alloy film) changes according to the magnetic field intensity and its output voltage changes correspondingly. Iron and steel are used to build vehicles, and they have greater magnetic conductance than the surrounding air. They polymerize the geomagnetic field and cause the magnetic field of nearby vehicles to increase exponentially. The magnetic field can be detected at the distance of 15m away from the vehicles. Thus using magnetic resistance sensor nodes disposed under the roadbed to monitor vehicles is feasible. The hysteresis characteristics can be used to detect traffic flow. This method is stable and effective and not be easily influenced by wet weather, temperature and the interference from pedestrians.

(4) Power supply module

Because electricity consumption determines the life span of a sensor node, energy efficiency should be considered in the design of software and hardware. Unnecessary module of nodes in various operating modes must be shut down to save energy.

The self-shutdown serial transceiver SP3223 is a transceiver that can automatically work or shut down according to the state of the serial cable connection. When there is no serial cable connection or data communications, the chip is in the shutdown state and its current consumption is only 1μA. The coordinator node is connected to the irrigation controller through RS232 serial interface in chip SP3223. The energy supply module, CR2032, is responsible for supplying energy to the entire node.

c. Wireless information sink node

The hardware structure of the sink nodes is the same as the traffic information collecting nodes and the only difference between them is in software configurations. The sink nodes are used to receive the data from traffic information collecting nodes and send them to traffic signal control nodes after data fusion. The communication between the sink nodes and traffic control nodes are via the SP3223 and the RS232 serial interface.

d. Traffic light control node

The traffic light control node has a low-power ARM processor of the S3C44B0X based on the ARM7TDMI-S, which is a cost-effective microcontroller solution scheme designed by Samsung for handheld devices and general applications. The S3C44B0X has all the advantages of the ARM processor, such as low-power consumption and high-performance. In the system, many modules are used, such as an 8-way 10-bit A/D converter module in the S3C44B0X, an LCD controller, a 32-bit timer, an UART, a GPIO, a PWM output module, etc. The traffic light controller node receives the data sent by the sink nodes, and a fuzzy neural controller located in it is used to determine the signal cycles, the phase differences and the green ratio at all directions on crossroads at the next stage. The S3C44B0X has up to 71 multi-function I/O ports, so the system has a high expansibility. Its hardware structure is shown Figure 4.

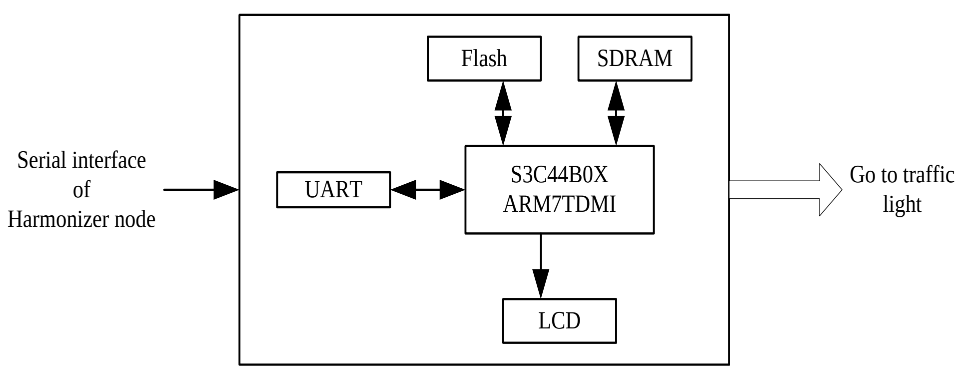

Figure 4. Structure of traffic light control node

f. Communication protocol

When designing a wireless sensor network, the first thing to be considered is low power consumption so that the network life cycle is extended as long as possible. In this paper, the IEEE802.15.4 standard and the ZigBee wireless network technology are used to design the wireless sensor network. The IEEE802.15.4 standard defines the physical layer and the MAC layer. The ZigBee defines the network layer protocol [8,9]. The ZigBee is a close range, low-complexity, low power, low data rate and low-cost two-way wireless communications technology which is suitable for the system. The primary energy consumption is for idle monitoring, receiving unnecessary data and retransmission of collisions, etc. Combining the characteristics of self-localization and RTC wake-up call in CC2431, the network uses the non-beacon access mode, namely the ALOHA CSMA/CA channel which can access the mechanism to reduce power consumption . The sensor node dialogues with the coordination node when required for data transmission only. It is in the sleep mode for the rest of the time in order to save power consumption while maintaining the network connection. Since each sensor node needs to transmit minimal information and the time in dormant state is longer than its working time, collision of information is almost unlikely.

IV. DESIGN OF RANK FUZZY NEURAL NETWORK CONTROLLER

The system includes two fuzzy neural network controllers: a green light delay fuzzy neural controller and a signal cycle fuzzy neural controller. They are located in the traffic light control node. The signal cycle fuzzy neural controller determines the signal cycles on the arteries according to the traffic flow and the green ratio measured at the crossings. The green light delay fuzzy neural controller adjusts the green ratio for each direction of the crossing according to the real-time traffic flow data at the crossing.

a. Green light delay fuzzy neural controller

(1) Controller Structure

Green light delay fuzzy neural controller takes a five-layer neuron network, as shown in figure 5.

The first layer is input one with two nodes. One node represents input variable (green light phase vehicle queue length P), while the other node shows another input variable (next green light phase vehicle queue length Q). They are not related to the weight on the second layer. Inspirit function of the nodes is

$$f(x)=x \qquad (1)$$

The second layer consists of membership function nodes with 14 neurons. They denote all fuzzy set of input language variable and accomplish mapping from accurate value to fuzzy value.

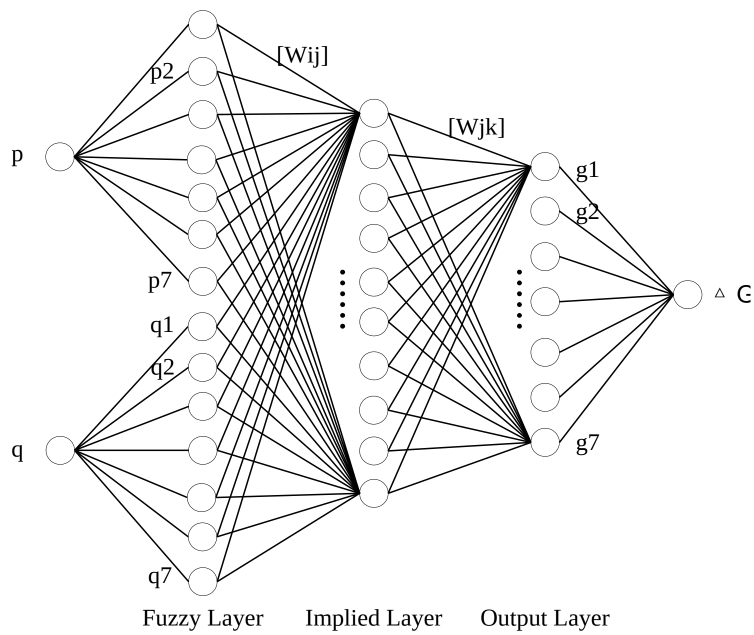

Figure 5. Neural Network Topological Structure

The third layer is implied one including 10 neurons. Implied layer takes charges of operating membership values from fuzzy layer to implement the process of fuzzy reasoning by means of the relation of input data and types.

The fourth layer is output one. The output is a membership function of input samples relative to green light delay △G, including 7 neurons. Connection weight [W_{ij}] and [W_{jk}] are trained to indicate the control rules. S curve is used as prompting functions for the third and fourth layers:

$$f(x)=1/(1+ exp(-x)) \qquad (2)$$

so the input and output of implied layer as:

$$U_j=\sum_{i=1}^{2} w_{ij}x_i -t_j \qquad j=1,2,...,10 \qquad (3)$$

$$V_j=1/[1+exp(-\sum_{i=1}^{2} w_{ij}x_i +t_j)] \qquad j=1,2,...,10 \qquad (4)$$

Where, w_{ij} is the power of the input layer to the implied layer; t_j is the threshold value of the implied layer, j is the number of the implied layer neurons[10,11,12] .
so the input and output of output layer as:

$$G_I= \sum_{j=1}^{10} w_{jk} h_j \ -t_p \qquad p=1,2...7 \qquad (5)$$

$$G_O=1/[1+exp(-\sum_{j=1}^{10} w_{jk} h_j \ +t_p)] \qquad p=1,2...7 \qquad (6)$$

Where, w_{jK} is the power of the implied layer to the output layer; t_p is the threshold value of the output layer, p is the number of the output layer neurons.

The fifth layer is defuzzification one. It completes the process of defuzzification for △G by the rule of largest membership to gain the accurate value of it.

(2) Foundation of Fuzzy Relationship

The fuzzy relation of fuzzy system, namely the library of fuzzy rules, may be stored by parallel through the study of neural network [13]. There are two inputs (P and Q) and an output (△G). The universes of discourse of input variables P and Q are {0, 2, 4, 8, 10, 12, 16, 18, 20}. The fuzzy set of P and Q are defined as {NB (very short), NM(short), NS(shorter), ZO(middle), PS(longer), PN(long), PB (very long)}. Membership function uses triangle, shows in Figure 6.

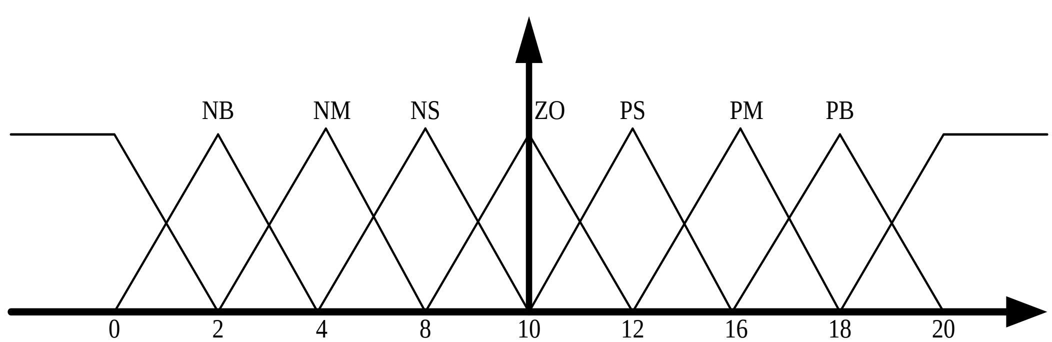

Figure 6. The membership degree of input var. P&Q

The universes of discourse of output variable △G are {0, 3, 6, 9, 12, 15, 18}. Its fuzzy set is defined as {NB (very little), NM (little), NS (less),ZO (middle), PS (more), PM (much), PB (very much)}. Membership function uses triangle also, shows in Figure 7

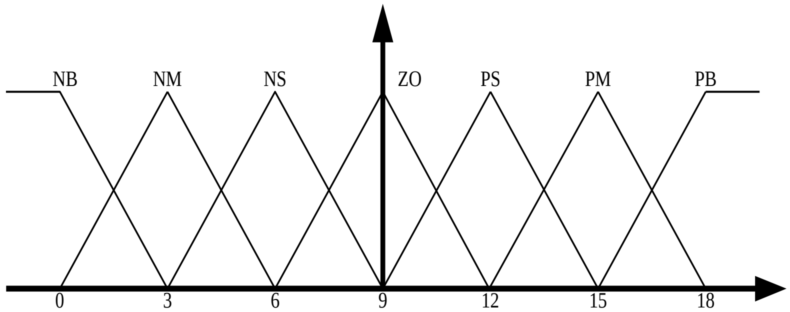

Figure 7. The membership degree of input var. △G

According to of control experiences of traffic policemen, the following green time delay fuzzy control rules can be summed up as shown in Table 1.

Table 1: Green time delay fuzzy control rule table

P	**Q**						
	NB	*NM*	*NS*	*ZO*	*PS*	*PM*	*PB*
NB	NM	NS	NS	NS	NS	NS	NS
NM	NM	NM	NM	NM	NS	NS	NS
NS	ZO	ZO	ZO	ZO	NS	NS	NS
ZO	PS	ZO	ZO	ZO	ZO	ZO	NS
PS	PM	PM	PM	PS	PS	PS	ZO
PM	PB	PB	PB	PM	PM	PM	PS
PB	PB	PB	PB	PB	PB	PB	PM

b. Signal cycle fuzzy neural controller

The task of signal cycle fuzzy neural controller is: determine the unified cycle used on artery at the next phase according to traffic flow and green ratio at previous phase in order to make vehicle queue length the least. In traffic signal control system, the cycle should keep the same in order to ensure harmonious traffic signals at artery and steady phase difference, accomplishing green wave control for traffic artery. In order to avoid the bottleneck effect, cycle should be determined by the crossing with the largest saturation. So the largest cycle on traffic artery is selected as public cycle, while fixed phase difference is taken between crossings on the traffic artery.

Signal cycle fuzzy neural controller has two inputs (saturation X and traffic flow ratio Y) and one output (cycle increment △C).

Saturation X is defined as:

$$X=Q/(\lambda S) \qquad (7)$$

Where, Q is vehicle traffic flow, λ means green ratio of the phase, S shows saturation flow.
Traffic flow ratio at crossing j is described as following:

$$\boldsymbol{R}_{jn}=\frac{\sum_{j=1}^{n} q_{jn\ i}}{s_{jn\ i}} \qquad (8)$$

Where, q_{jmi} is traffic flow at crossing j, cycle m and phase i; s_{jmi} represents saturation flow; n means the number of phases.
Y is the largest value of traffic flow ratio at all crossing, namely:

$$Y=MAX\ \{R_{jn}, j = 1,2,3,\ldots\} \qquad (9)$$

The universes of discourse of input variable X and Y are {0.40, 0.55, 0.70, 0.80, 0.90, 0.92, 0.94, 0.96, 0.98}. 7 language values are selected for them: PB(positive big),PM(positive middle), PS(positive small), ZO(zero), NS(negative small), NM(negative middle), NB(negative big). Membership function uses triangle, shows in Figure 8.

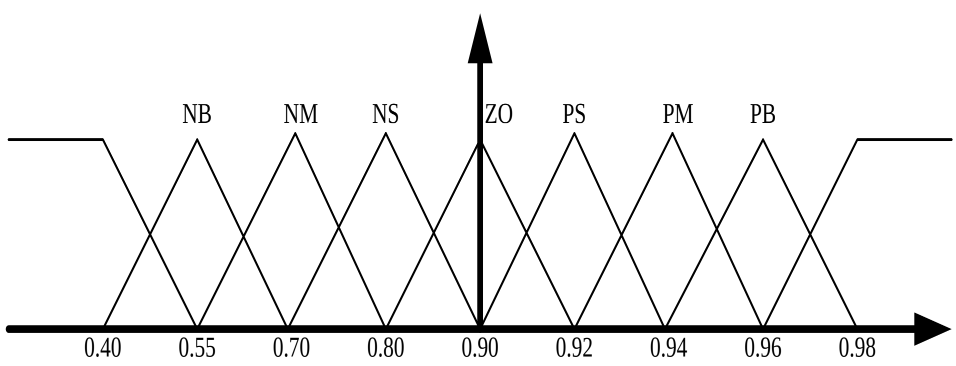

Figure 8. The membership degree of input var. X&Y

The universes of discourse of cycle increment △C are {-8, -6, -4, -2, 0, 2, 4, 6, 8}. 7 language values are selected for them: PB(positive big), PM(positive middle), PS(positive small), ZO(zero), NS(negative small), NM(negative middle), NB(negative big). Membership function uses triangle, shows in Figure 9.

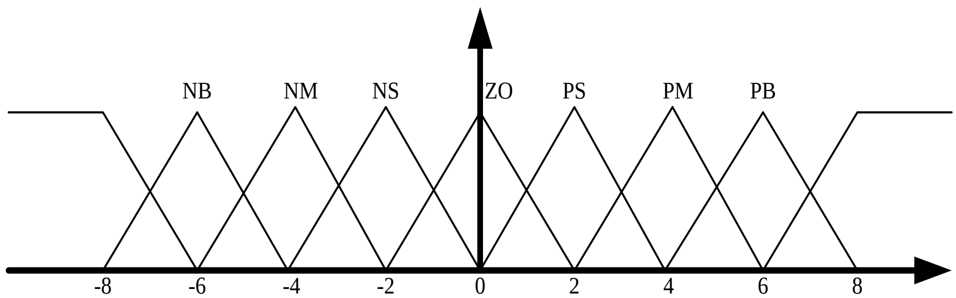

Figure 9. The membership degree of input var. △C

A large number of research and application indicate that adjusting cycle time should keep saturation reach around 0.9, while at this point traffic ability is the largest and delay is the smallest. Experience shows, as saturation is small than 0.9, cycle should be reduced to improve the traffic efficiency at crossings, otherwise cycle should be increased. Meanwhile, when traffic flow is bigger, cycle should be increased. On the contrary, when traffic flow is smaller, cycle should be reduced.

According to of control experiences, the following cycle increment fuzzy control rules can be summed up as shown in Table 2.

Table 2: Cycle Increment Fuzzy Control Rules

X	**Y**						
	NB	*NM*	*NS*	*ZO*	*PS*	*PM*	*PB*
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NM	NM	NS	NS	NS	ZO	ZO
NS	NM	NS	NS	ZO	ZO	PS	PS
ZO	NM	NS	ZO	ZO	ZO	PS	PS
PS	NS	NS	ZO	ZO	PS	PS	PM
PM	ZO	ZO	PS	PS	PM	PM	PM
PB	ZO	ZO	PS	PM	PM	PB	PB

The neural network model of the green light delay controller has the same structure as the signal cycle controller with a five-layer neuron network, as shown in figure 4. Input of the network is saturation X and traffic flow ratio Y, its output is cycle increment △C. While similar train method can be used, all the fuzzy rulers can be stored by weights of the network.

V. COMPUTER SIMULATIONS

Provided there is a highway including three crossings, where east-west direction is the artery, while south-north direction is the branch. Saturation flow on artery is 3600 PUC/h, while Saturation flow on branch is 1800PUC/h. The distance between each two crossings is 600M, as shown in Figure 10. Traffic flow of reaching vehicles obeys Poisson distribution, while traffic flow of leaving vehicles obeys negative index distribution. Proportion of traffic flow for turning left and going straight and turning right is 1:2:1.

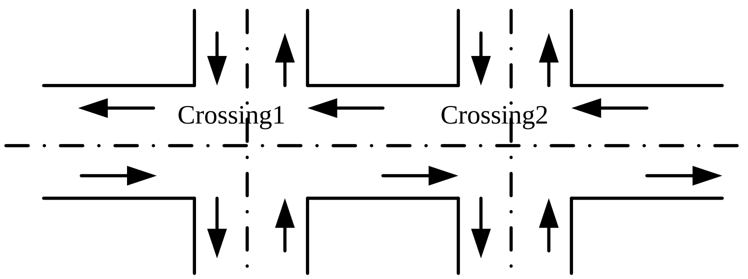

Figure 10. Diagram of three crossings on artery

We developed a program by VC# to make a simulation in different traffic flow200、 400、600、800、1000、1200、1400、1600、1800、2000/h for the control method mentioned above. For the each traffic flow, we simulation 10 times, simulation time for each time is 40 minutes. Then, we have compared it with the fuzzy control methods [13]. So we obtain the results of 10 simulations as shown in Table 3.

Table 3: Simulation result comparison

Times of Simulation	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Traffic Flow	200	400	600	800	1000	1200	1400	1600	1800	2000
General fuzzy control	0	0. 15	0.36	0.78	2.01	4.06	7.21	11.75	18.74	>20
This paper	0	0.10	0.22	0.52	1.43	3.01	4.12	8.66	12.84	18.95

From Table3, we notice that the new control has no obvious advantage comparing with ordinary controls. But when the traffic flow gets heavier, the average queue length is reduced obviously by the new control. Vehicle average delay reduces 11.9%.

VI. CONCLUSIONS

In this paper, we introduced wireless sensor network and fuzzy neural network into traffic signal control system and took use of hierarchical control method to accomplish intelligent control on traffic artery. The system took advantages of wireless sensor network, such as low consumption, self-organization, distributed computing, to complete quick vehicle data acquisition. Meanwhile, by use of fuzzy neural network, the system has achieved a good immediacy and control precision, while greatly reducing vehicle delay.

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